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DIRECTIONAL PROPERTIES OF EXTENSIVE AIR SHOWER ARRAYS

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ABSTRACT. The simple extensive air shower array proposed by Shen and Singer (1957) for which they claimed about 90% directional efficiency, has been tested by two groups of physicists, McCusker *et al.* (1959) and Layson *et al.* (1960), using it in conjunction with cloud chambers and scintillation counters, respectively. They concluded that the proposed set up has got very poor efficiency in selecting showers in preferred directions. It is pointed out that there are some significant differences between the results of various authors on this problem and that it is possible to make further improvements in the performance of the device, besides the two methods suggested by McCusker *et al.* (1959).

INTRODUCTION

Shen and Singer (1957) proposed a simple extensive air shower array consisting of three G. M. counter telescopes, placed at the vertices of a triangle, for which they claimed a directional efficiency of 90%. This arrangement has been tested by McCuker *et al.*, (1959) using a similar unit in conjunction with two cloud chambers. From their experimental results they concluded that there is no great improvement in the angular resolution of the apparatus suggested by Shen and Singer, and it is not of much value in looking for anisotropy in the high energy primary cosmic radiation. Their results indicate that the vertical arrangement leads only to 7% (or at the best 14%) enrichment of showers coming from the near vertical direction. But our results (Bhaskara Rao and Gill, 1960), obtained during the course of an investigation on the influence of geomagnetic field on extensive air showers at Gulmarg, suggest an enrichment value of the order of 55%. With a view to check our Gulmarg data, a similar experiment has been conducted at Aligarh (alt. 680 ft.), again with two telescopes. The experimental results give an enrichment figure of 54% which is very high when compared to that of McCusker *et al.* Moreover, McCusker *et al.*, contented that there is no serious disagreement between their own results and those of Shen and Singer. Even this contention is not justifiable as shown at a latter stage. Further, their results are in disagreement not only with our results, but also with those of Shen and Singer and of Rathgeber (1959). Although the experimental results of Layson *et al.* (1960) agree well with their theoretical calculations, their shower data do not seem to follow the well established $\cos^n\theta$ law. Finally, whatever might be the actual directional efficiency and usefulness of the shower array proposed by Shen

and Singer, the observed discrepancies are very significant and worth consideration. Further slight improvements can be made in the device.

EXPERIMENTAL

The arrangement used consisted of two G.M. counter telescopes of semiangle 10°, with two trays in each. Each tray consisted of four counters connected in parallel. The telescopes could be tilted independently around any axis. All other details of the experiment were exactly the same as mentioned in our paper (Bhaskara Rao and Gill, 1960).

The separation between the telescopes was 40*m*. Fourfold coincidences were recorded in the East-West and North-South planes, the telescopes being fixed in three positions, vertical, 45° zenith angle and horizontal, in rotation. The position of the telescopes was changed from the E-W plane to N-S plane and vice versa for every twenty days. The data were corrected for pressure and temperature variations using $\beta = -10\%$ cm^{-1}Hg., and $\theta_T = -0.38\%$ per degree C, respectively. Then the average of the shower rates in the two planes was calculated.

RESULTS AND DISCUSSION

Here four instances are given, including our own results at Aligarh, to point out the large discrepancies between the results of various authors.

(A) The shower rates corresponding to 40 *m* separation of the telescopes were given in Table I.

TABLE I

Coincidence rate vs. zenith angle

Zenith angle 'Z'	Average coincidence rate per hour
0°	4.98±0.08
45°	3.69±0.07
90°	2.30±0.06

Percentage enrichment $= \frac{V-H}{V} \times 100\% = 54\%$

Where V = Coincidence rate with telescopes in the vertical position,
H = Coincidence rate in the horizontal position.

Here it should be remembered that the experimental results of McCusker *et al.*, actually give only 7% enrichment which is very low when compared to our value of 54%.

(B) Some of the experimental results of Rathgeber,

TABLE II

Shower rate in counts per hour

Zenith angle 'Z'	Counters in each telescope.	
	(X) 2 counters	(Y) 3 counters
0°	1.96±0.29	1.56±0.27
90°	1.25±0.23	0.77±0.16

From the columns (X) and (Y), enrichment values can be calculated as 36% and 51% respectively. Evidently, there is large difference between the enrichment values of McCusker *et al.*, and Rathgeber.

(C) Comparison of the experimental results of Shen and Singher and McCusker *et al.*

TABLE III

Experimental determination of zenith angle distribution

Separation between the extreme counters in cms.	Effective zenith angle	Difference of effective zenith angle	Six fold coincidence rate per hour	Percentage difference in the coincidence rate.
		Shen and Singer		
(i) 46.2	6.3°	13.2°	0.30±0.020	
(ii) 14.8	19.5°		0.46±0.025	55%
		McCusker *et al.*,		
(i) 67.0	5.6°		0.605±0.039	
(ii) 15.0	24.8°	19.2°	0.692±0.029	14%

The experimental set up used by McCusker *et al.*, was just similar to that of Shen and Singer. Shen and Singers' results show a difference of 55% in the counting rate for a difference of 13.2° in the effective zenith angle, whereas those of McCusker *et al.*, show only a variation of 14% for 19.2° difference of effective zenith angle. In fact McCusker *et al.*, should have observed a difference larger than 55%. Moreover, McCusker *et al.*, contented that their experimental results are not in serious disagreement with those reported by Shen and Singer. From the above table it is easy to see how they are not justified in their contention.

(D) Experimental results of Layson *et al.*,(1960) :

The directional response of the same set up was also tested by Layson *et al.*, using it in conjunction with the Sydney air shower apparatus. Although they claim that their experimental results are in good agreement with their theoretical calculations, their data do not seem to follow the well known $\cos^n\theta$ law. The zenithal distribution of showers given by them in the form of histogram, (corres-

ponding to all showers) is compared with the distribution obtained by McCusker *et al.*, with the help of cloud chambers. Even if the directional efficiency of the system were to be low the observed data should have followed the $\cos^n\theta$ law. Data obtained by McCusker, *et al.*, follows the theoretical distribution well, but the histogram given by Layson *et al.*, is much different from what it ought to be. From Fig. 1(b) it can be seen that the telescopic system records more showers at larger zenith angles (from 5°–40°, at an interval of 5°) than from the vertical and near vertical i.e., 0°–5°. In particular the shower rate at 20°—25° is four times the rate at 0°–5°. This discrepancy is of very serious nature, which requires

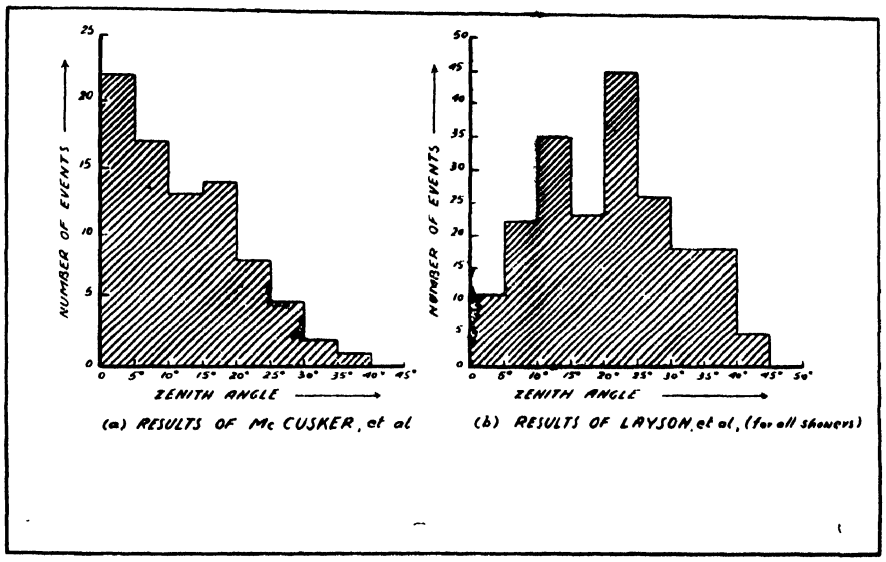

Fig. 1. The frequency of showers of different zenith angles setting off the arrangement.

some explanation. Rossi (1960) attributed the flat distribution of showers observed at Alto (alt. 4100m; shower size ($10^7 < N < 3 \times 10^7$) to the fact that the showers are still near their maximum development. But the same arguments cannot hold good in the case of showers recorded at Sydney.

In view of the significant discrepancies in the experimental results of McCusker *et al.*, and other workers, and the irregularities of basic value in the zenithal distribution of showers recorded by Layson *et al.*, one should be cautious in drawing a quantitative conclusion regarding the directional efficiency of the shower array. It is to be emphasized that the directional efficiency of an array decreases at larger zenith angles because of the nonuniformity of the side shower background. McCusker *et al.*, suggested two ways to improve the performance of the device. This can be still improved by using sets of two or more counters connected in parallel, in the telescopes, instead of single counters, at the same time keeping the aperture of the telescopes constant by adjusting the separation between the upper and lower sets suitably. This offers larger sensitive area for shower particles

coming within the defined aperture of the telescopes and helps in reducing the percentage background of side showers from zenith angles, other than the defined aperture, in which we are not interested. This background can also be reduced by increasing the multiplicity of coincidence from six to nine, with a third set of counters in between the upper and lower sets of each telescope. These modifications do not have any significant effect on shower particles falling within the defined angle, but considerably reduce the background.

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